A MODELING TOOL FOR EVALUATING RESERVOIR OPERATIONS IN THE MUSKINGUM BASIN

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ABSTRACT The Huntington District Corps of Engineers together with GKY & Associates, Inc. has developed a modeling tool to evaluate the effect of various changes in reservoir operations in the Muskingum River Basin. This modeling tool helps the Corps evaluate the trade-off between potentially conflicting interests, such as structural safety, flood control, water supply, recreation, and ecology. This paper briefly describes the logic in the Muskingum River Basin Model, and shows the potential effect of two changes in reservoir operation.

INTRODUCTION

Recent concerns about structural safety, flood control, water supply, recreational uses, ecology, etc within Muskingum River Basin have prompted the Huntington District Corps of Engineers to develop a model to evaluate potential changes in reservoir operations. Many of these concerns were identified in a series of meetings and interviews with interested stakeholders.

The Muskingum River, which drains approximately 20,851 sq km (8,051 sq mi) of southeastern Ohio, starts about 25 miles south of Lake Erie, flows in a southerly direction, and empties in the Ohio River about 170 miles below Pittsburgh near Marietta, WV. This study concerns the sixteen managed lakes and thirteen downstream flow controls in the Muskingum Basin shown in Figure 1. The lakes include Atwood, Beach City, Bolivar, Charles Mill, Clendening, Dillon, Dover, Leesville, Mohawk, Mohicanville, North Branch Kokosing, Piedmont, Pleasant Hill, Senecaville, Tappan, and Wills Creek. The downstream controls (gages) include Cambridge, Coshocton, Derwent, Dresden, Loudenville, McConnelsville, Melco, New Philadelphia, Newcomerstown, Tippecanoe, Uhrichsville, Walhonding, and Zanesville.

This paper presents a few examples of how the Corps and GKY & Associates, Inc. (GKY&A) use a model to simulate different operating rules for these sixteen reservoirs. This paper will highlight some of the conflicts involved with improving lake operations. Future studies will evaluate special operations for canoeing and improving ecology.

Figure 1 Schematic of the Muskingum River Basin.

MODEL DESCRIPTION

The computer model used for this study was developed by Corps and GKY&A, and uses High Performance Systems, Incorporated STELLA software. STELLA is an object oriented modeling tool. See Stein et al. (2003) for more information about the model interface and the post-processor.

For each lake the Huntington District (Corps) supplied the following data: desired summer pool elevation; desired winter pool elevation; desired pool transition periods; minimum discharge for summer and winter; maximum discharge for summer and winter - without directive; stage-storage curves; siphon and orifice curves, where applicable; spillway crest elevations; and historical total inflow, incremental inflow, outflow, and elevation data from January 1, 1962 to June 30, 2005. For each downstream control the Corps supplied the following data: travel-time from contributing lakes (the model rounds travel time to the nearest day since it uses a daily time step); maximum flow for summer and winter; and historical total flow and incremental flow data from January 1, 1962 to June 30, 2005.

Model Logic

Three of the projects in the basin (Dover, Mohawk, and Wills Creek) receive inflow that is managed by other (upstream) projects, and eight of the projects (Atwood, Clendening, Leesville, North Branch Kokosing, Piedmont, Pleasant Hill, and Tappan) have siphon releases. Three groups of projects (the Dover group, the Mohawk group, and the Tappan-Clendening-Piedmont group) have special operating rules to regulate their combined release, and Pleasant Hill and Charles Mill have special operating rules to facilitate whitewater rafting downstream. Moreover, all of the projects have operating rules to mitigate flooding at downstream gages (including the Ohio River), to restore or maintain a desired pool elevation, and to store or release water for various withdrawals (e.g. for local water supply needs). One of the most urgent concerns addressed in this study is that four of the projects (Beach City, Bolivar, Dover, and Mohawk) now have structural deficiencies that limit the maximum pool that these structures can safely withstand. Thus, these four projects also have special releases designed to mitigate exceeding their respective project geotechnical threshold (PGT) elevation (i.e. the pool elevation likely to induce structural failure).

The model uses daily inflow values, downstream control point incremental flows, and a series of operator supplied control parameters to simulate the daily operation of the lakes. Lake storage and other low flow purposes are defined by the upper limiting guide curve. The program will release all inflow, subject to flood control requirements, when the lake elevation is at or above the upper limiting guide curve. When the lake elevation is below the upper limiting guide curve, the program determines the amount of inflow which may be stored if the inflow is greater than the required low flow demand, and if the inflow is insufficient for these purposes, the program determines the amount of flow to be released from storage to make up the release shortage. The program also allows the lake to be operated for downstream control points if a minimum flow at the downstream control locations is desired. A macro in Microsoft Excel is used to easily manipulate the model output for post-processing. Thus, the model simulates lake releases in response to seasonally based operational controls and historical inflow data.

Cost of Flood Damage

The Corps also supplied data relating critical stages at nineteen locations to damage costs, and data relating flow to stage at these locations. All of the damage locations correspond to either a project outflow or to a gauge that is simulated in the model. Several components were then added to the model to compute the damage at each location in the following way.

1. Test whether the flow control at each damage location (during a time step) has been exceeded.
2. If a damage location has an exceedence, then convert the exceedence flow to a stage.
3. Convert these stages to damage costs.
4. Accrue the “event” damage over the period of record, where the damage associated with an “event” is the maximum value in any continuous sequence of damage values.

MODEL VALIDATION

The current downstream control discharges and lake operation parameters were employed to generate results from the STELLA model. The simulated and actual historical flows and lake storages were visually compared and verified for accuracy. For example, Figure 2 shows the observed and modeled lake stage for the fifteen-year validation period (January 1, 1988 to May 31, 2002) for Senecaville Lake. Figure 3 shows the observed and modeled gage flow for Coshocton gage, a downstream control point for 13 of the 16 project lakes. The model followed observed data very closely.

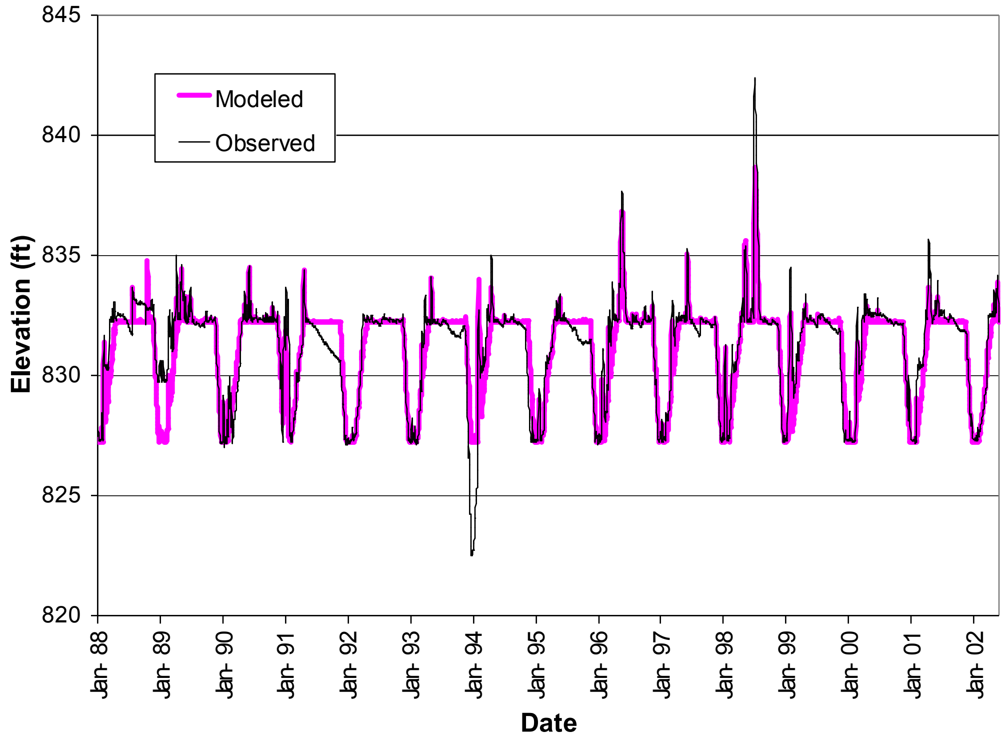

Figure 2 Observed versus modeled elevations for Senecaville Lake.

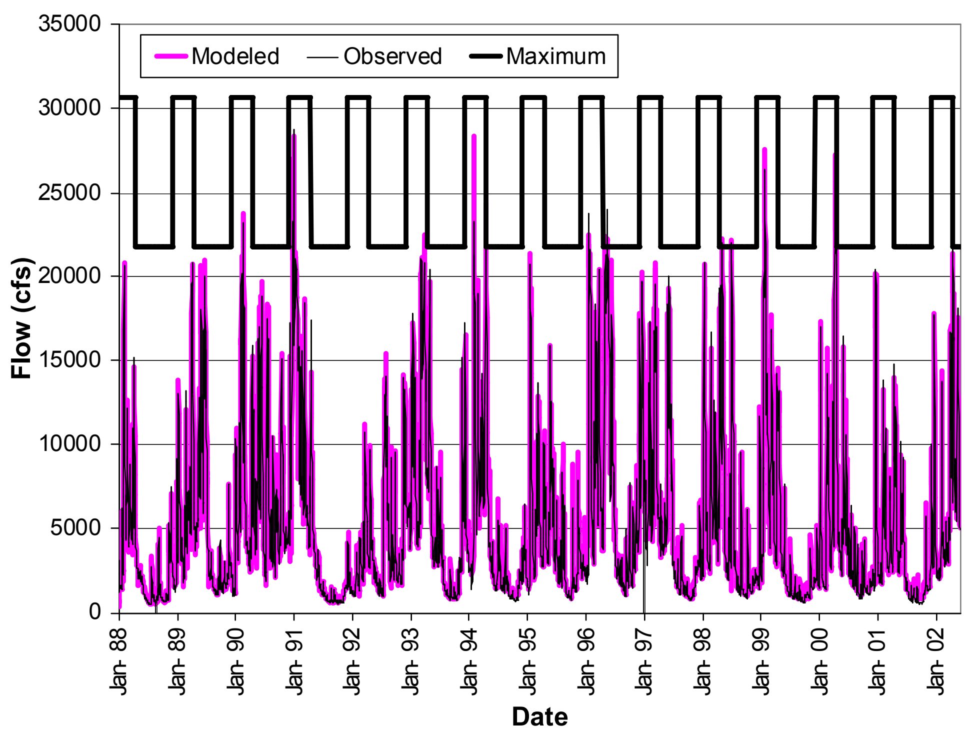

Figure 3 Observed versus modeled flows for Coshocton Gage.

MODEL IMPLEMENTATION

The Corps of Engineers and GKY&A recently compiled a list of operation alternatives to be evaluated with the model described in the previous section. These alternatives generally evaluate the effect of implementing the following objectives.

1. Introducing special releases in an effort to prevent the pool elevation from exceeding the critical PGT pool elevations at the four projects already mentioned.
2. Increasing or decreasing various target pool elevations or flow controls to mitigate bank erosion, flooding, and/or sedimentation problems.
3. Calculating the storage allocation required for anticipated water supply needs at several projects (Atwood, Tappan, Senecaville, Wills Creek, and Pleasant Hill).

The following subsections will briefly describe model results for two of these alternatives.

Cost of Protecting Structural Deficiencies

The first alternative listed above involved introducing a trigger elevation at Beach City, Bolivar, Dover, and Mohawk, which must be set below the project's PGT elevation in order to be effective. The trigger logic dictates that any time the pool elevation exceeds the project's trigger elevation, the project begins to release its maximum outflow capacity – regardless of the downstream flow controls, in an effort to avoid project failure. The baseline for the following model comparisons is a scenario where all four trigger elevations are set to their maximum values, which is termed "Spill+5" to indicate an elevation that is 5 feet above each project's spillway crest. In other words, the baseline is a model scenario in which the full-release triggers have no effect on the model performance. In effect, this value provides a base condition for this alternative which represents the period of record without PGT releases. In the second model scenario, termed "PGT", all four full-release triggers are set at their respective PGT elevations. The third and fourth scenarios, termed "PGT-2" and "PGT-4", refer to all four trigger elevations being two and four feet below each project's PGT elevation. In the last scenario, termed "Optimum", the trigger elevations are adjusted to prevent each project's maximum pool elevation from exceeding its respective PGT elevation during the 43.5-year simulation (i.e. 1/1962 – 6/2005).

Figure 4 shows how decreasing the trigger elevation (i.e. left to right along the x-axis) *decreases* the number of PGT exceedences (i.e. days of potential structural failure, on the left y-axis), and *increases* the basin-wide damage caused by flooding at downstream gages (i.e. right y-axis) at these four projects. Table 1 furthermore lists the change in damage (with respect to the baseline scenario, "Spill+5") that occurred at each location that changed. These results clearly show that protecting these structural deficiencies is expensive in the long-run, and may justify the cost of rehabilitation or replacement.

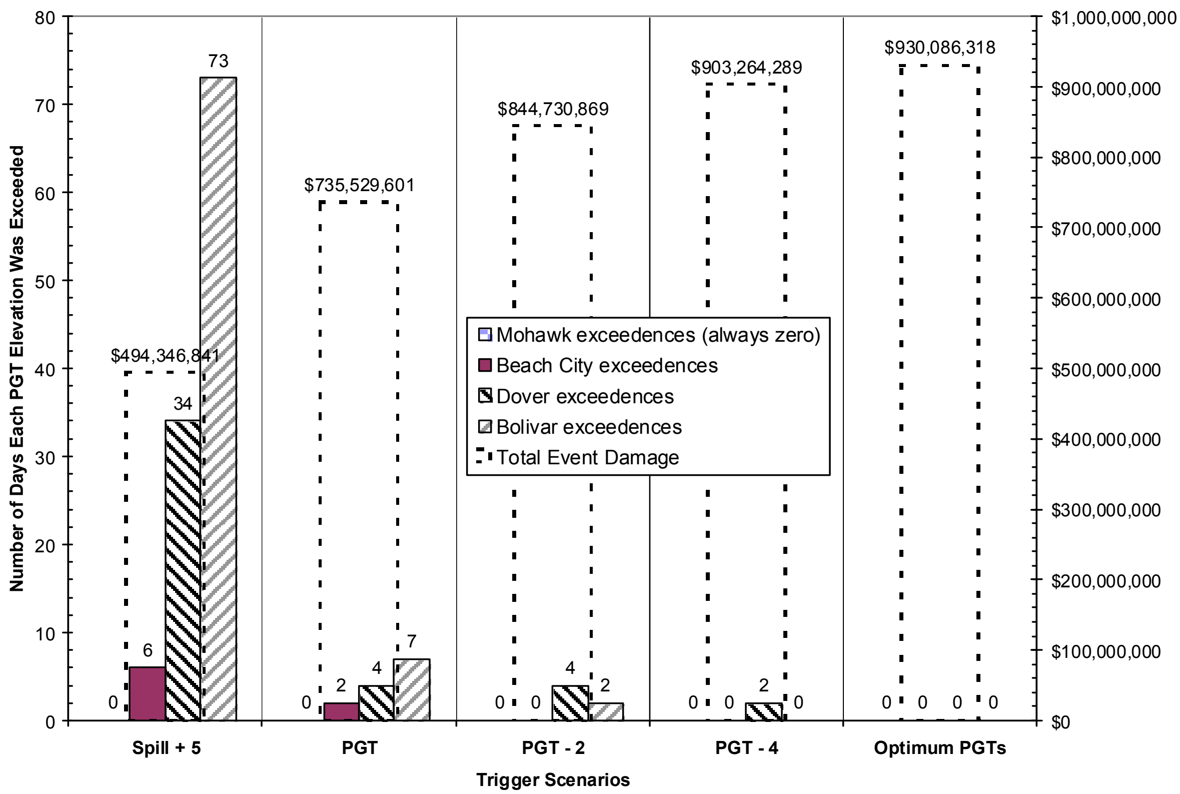

Figure 4 PGT exceedences and downstream damage versus trigger elevation.

Table 1: Increase in damage for trigger scenarios at pertinent gage/project locations

Gage Location	Trigger-induced Increase in Flood Damage for Each Trigger Scenario			
	PGT	**PGT – 2 ft**	**PGT – 4 ft**	**Optimum**
Beach City	+$14,959,039	+$23,916,511	+$41,831,455	+$23,916,511
Coshocton	+$17,736,491	+$28,485,457	+$37,981,299	+$35,871,684
Dover	+$25,047,924	+$38,652,795	+$45,455,231	+$52,257,666
Dresden	+$9,076,905	+$9,030,625	+$9,862,578	+$10,765,245
McConnelsville	+$5,359,361	+$7,898,811	+$8,054,983	+$7,789,269
New Philadelphia	+$38,835,782	+$57,492,493	+$60,244,561	+$70,058,336
Newcomerstown	+$97,139,799	+$148,772,998	+$172,244,178	+$200,406,196
Zanesville	+$33,027,458	+$36,134,339	+$33,243,163	+$34,674,569
Basin-wide	**+$241,182,760**	**+$350,384,028**	**+$408,917,448**	**+$435,739,477**

Storage Allocation for Water Supply Withdrawals

The third alternative listed above involves comparing four different scenarios: one with no lake withdrawals for water supply (the baseline), one with a two MGD (million gallons per day) withdrawal from the five projects, one with a six MGD withdrawal at the five projects, and one with a ten MGD withdrawal at the five projects. These three fictitious withdrawal rates represent small, moderate, and large demands on the Muskingum basin. This alternative had a relatively insignificant effect on the damage in the basin (<<1% decrease basin-wide). Figure 5 shows how each withdrawal rate effects the pool elevation at Pleasant Hill during a 50-year drought (i.e. "Min 2%" ≡ 1 / 50 years). Note that even without any lake withdrawals (i.e. the "Baseline" scenario) Pleasant Hill struggles to maintain the ideal ("Rule") elevation during a 50-year drought. Thus, adding a two, six, or ten MGD withdrawal during a drought stresses the lake even further. Table 2 shows the maximum amount of lake storage required to supply these three withdrawal rates during a 50-year drought. Thus, these results suggest that lake withdrawals at Pleasant Hill may be particularly detrimental to recreational or aesthetic interests that depend on a stable pool elevation.

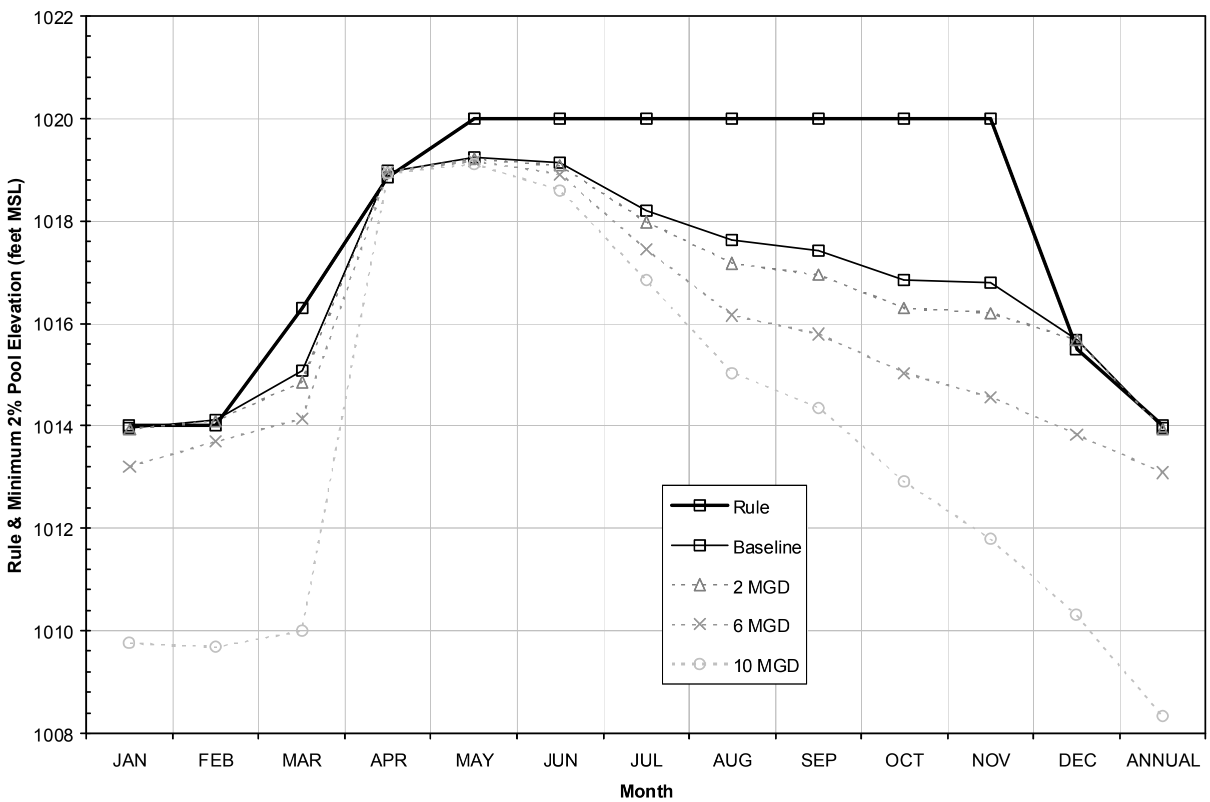

Figure 5 Ideal/rule versus the pool elevation during a typical 50-year drought with various lake withdrawals.

Table 2: Storage allocation for each withdrawal scenario.

Project	Storage Allocation* (acre-ft) for Each Withdrawal Rate		
	Q = 2 MGD	**Q = 6 MGD**	**Q = 10 MGD**
Atwood	306.42	925.48	2131.25
Tappan	403.00	1255.02	2390.98
Senecaville	352.46	1654.47	3238.67
Wills Creek	9.99	185.33	737.77
Pleasant Hill	431.40	1584.07	3384.65

* The maximum reduction in the monthly minimum 2% storage, with respect to the baseline scenario (no withdrawal for water supply).

CONCLUSIONS

The model developed by the Corps and GKY&A provides a quick and accurate modeling tool to evaluate different alternatives for operating the sixteen reservoirs in the Muskingum River Basin. This paper shows that this modeling tool is useful for quantifying flood damage, flooding at downstream gages, lake storage allocations, and other lake elevation and flow statistics. It especially shows the cost associated with special PGT releases, and the storage allocation required for water supplies. Thus, this tool allows the Corps to evaluate how a change in operation that is designed to benefit one group of stakeholders will affect other stakeholders.

REFERENCES

Stein, S.M., Martin, B., Gorugantula, S., Smith, S., Webb, J., Stout, S.M. (2003). "Water Supply Study for the Muskingum Watershed," Conf. Proc. paper, World Water & Environmental Resources Congress 2003 and Related Symposia, Philadelphia, Pennsylvania, 9 pgs.